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MANAGEMENT OF RECYCLED WASTE-PROCESS WATER PONDS

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Demonstration Grant No. WPD 117-01-66

1. MANAGEMENT OF RECYCLED WASTE-PROCESS WATER PONDS

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First Year of Study --
December 1, 1965 to November 30, 1966

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2. Summary Statement of Progress:

Studies of the Black and Decker Manufacturing Company's process water pond at Hampstead, Maryland, during the summer and autumn of 1966 show that it is possible to reduce the nutrient nitrogen levels of stored treated waste waters by alternate thermal stratification and mixing. Secondary treated domestic waste is stored in the pond and recirculated for manufacturing uses. This pond thermally stratifies during the relatively bright and warm daylight period and surface waters supersaturate with dissolved oxygen. The lower layers become oxygen deficient. During the night the pond is stirred by sparged air. Storage times permit biological nitrification of ammonia in the waste; this serves as a source of oxygen to dissolved oxygen depleted strata. Nitrogen is lost from the system as nitrogen gas by biological denitrification of nitrates and nitrites.

An office trailer laboratory has been established at the pond. Automatic sampling and analytical equipment is being developed for a more detailed study during the open weather of 1967.

Studies of the compatibility of process pond water for coolant make up were made.

The decomposition of forest leaves carried into the process pond was investigated.

A literature survey of pertinent studies has been completed, and a mathematical formulation of the economics of waste water re-use has been developed.

3. Concise Statement of Progress

Reuse of Treated Sewage for Manufacturing Process Water

Report of First Year's Studies under
Demonstration Grant No. WPD 117-01-66
Year Ending November 30, 1966

1. Purposes of Demonstration Grant Project: This study was established to make a detailed examination of the operation of the treated waste water fed process water system of the Black and Decker Manufacturing Plant at Hampstead, Maryland.

With the expansion of the Hampstead plant during late 1965 the domestic waste loading discharged to treatment and to process pond water storage was nearly doubled from a three shift population of 1800 to 3000 workers. The rates of water reuse were also increased. This afforded an opportunity to examine the behavior of a relatively simple and economical process water reuse system under extreme conditions.

The purpose of this study is to develop principles that may be generally applied to other industrial communities where limited water resources force the reuse of treated domestic waste waters. The Black and Decker Manufacturing Company's water reuse program has been a practical success. This study is designed to discover the conditions required for transfer of practice to other water short communities undergoing industrial development. The reuse of waste waters may be applied to conserve the quality of limited surface waters and expand the range of water uses available to water short areas.

2. Findings from First Year of Study: The most important set of observations from the first year's study are

those showing that it is possible to combine bacterial nitrification and denitrification in the same storage pond so that the nutrient concentration of the stored waste water may be greatly reduced. This process decreases the likelihood of (a) hydrogen sulfide production in the stored water mass, (b) algal nuisance, (c) the development of worm, snail, insect larvae, and snail infestations, (d) bacterial sliming of distribution line surfaces, and (e) offensive odors in the process waters.

In the Hampstead plant pond, the two processes are controlled by (a) the photosynthetic production of oxygen at rates exceeding the biological and chemical demands of the wastes added to the pond, (b) the mixing in of high concentrations of dissolved oxygen developed in the surface waters of the pond by mechanical aeration applied during the dark hours of the day, and (c) the reduction of nitrate in the deeper, light free hypolimnion during daylight hours when thermal stratification develops.

This sequence has been going on for some time unobserved. It appears to account for the success of the process water system used at Hampstead plant. A sequence of fortunate observations made during the record drought summer of 1966 provides the first description of the steps involved and of the conditions required to improve the qualities of waste waters by biologically robbing them of nitrogen.

3. Nitrification-Denitrification in Black and Decker Manufacturing Company Process Water Pond - Recirculation System: It is possible to reproduce the conditions that operate in the process water pond at the Hampstead plant in most areas of the temperate zone. Some

changes in depth and retention time may be required, but these may readily be approximated. A brief description of the working of the Hampstead plant system will provide a useful approximation of the functions that must be developed in other sites.

First, essentially all of the fresh water that enters the pond is derived from three wells (currently five). This fresh water is directed through the domestic uses of the plant and certain critical industrial applications. During the summer of 1966, the wells supplied from 15,000 to 240,000 gallons of water per day (mean 150,000 gallons per day). Approximately half of this served toilets and washrooms, and an eighth served drinking fountains and cafeteria uses. The remainder was used in critical plant and miscellaneous applications and losses, so that approximately two-thirds of the supply, the domestic waste water, passed through secondary biological waste treatment consisting of Imhoff tank settling and digestion, high rate trickling filter treatment, secondary settling, and chlorination before discharge to the process water pond. (Other fresh waters and all recirculated process water entered the pond without treatment.)

The process water pond itself is a small lake of approximately nine acres area, containing 11.5 million gallons when filled. The pond was formed by clearing, conditioning and damming up a swampy depression fed by a small creek in a low section of the plant property. The pond collects storm runoff as well as treated domestic wastes and recirculated process water. (During the summer of 1966 unusually dry weather prevailed, and storm waters made no contribution to the system.)

A series of 24 hour studies of the vertical distribution of temperatures and dissolved oxygen in the process water storage pond show that the pond typically becomes thermally stratified by 10:00 a.m. (following shut off of air stirring at 6:00 a.m.) and that the water below the thermocline loses oxygen rapidly thereafter, usually becoming oxygen depleted by noon or shortly after.

When stirring is applied at 6:00 p.m., vertical mixing is usually complete by 10:00 p.m. but oxygen deficiencies persist.

A preliminary oxygen budget shows that most of the oxygen found in the pond is produced by photosynthesis -- supersaturation values of 300 per cent are common during the daylight in the upper five feet of the pond. Oxygen transferred by air mixing and atmospheric exchange is negligible.

Bacteriological nitrification processes go on independently of light; they are moderated by temperature and by concentrations of ammonia. Denitrification of nitrite and nitrate to nitrogen gas, on the other hand, takes place only when the dissolved oxygen supply has been depleted, that is, during the late afternoons of days in which thermal stratification prevails.

The overall behavior of the process water pond is conditioned by (1) climate, (2) light, (3) shape of the basin, and (4) retention time or half life of the contained water.

The summer of 1966 represented an extreme situation that exaggerated the relative roles of thermal stratification, photosynthetic oxygen production, nitrification, and denitrification. From June to early September, no rain fell, and the pond operated at

roughly two thirds volume, with maximum half life -- roughly ten days. In this clear, bright, warm period, stratification was intense during the day. Process water volume of the pond was recycled approximately 15 times through the plant during the drought period of 120 days. In this interval, no water passed over the spillway.

During this period of retention, the treated waste entering the pond should have generated total nitrogen concentrations in the order of at least 25 ppm. (The materials balance data is incomplete, but the above nitrogen concentration represents a low approximation based on available samples, population, and water uses.) The concentrations of total nitrogen found in the pond at any level rarely exceeded 5 ppm, and the larger part of this (4.0 to 4.5 ppm N) existed as nitrate and nitrite.

It is clear that an active nitrogen losing mechanism exists in the pond.

The most plausible explanation (which will be examined in detail during the 1967 season) is that ammonia discharged in the treated waste water, and generated by breakdown of organic nitrogen in the waste and dead organisms in the pond, is biologically oxidized to nitrite and nitrate. This is possible because of (a) the long residence time of the treated waste water in the recycled system and in the pond, (b) availability of oxygen produced by photosynthesis and adsorbed from the atmosphere during stirring, and (c) active soil contact with the relatively large areas of the pond bottom.

The observable fact of importance was the absence of hydrogen sulfide in the process water taken from the bottom of the pond. Sulfate

is present in this water and hydrogen sulfide should be produced by biological reduction in the absence of oxygen. Zero oxygen concentrations prevail for roughly six hours per day in slightly less than half of the volume of the pond -- during the period of thermal stratification of bright summer days.

The nitrate present carries with it biologically available oxygen which bacteria utilize in the oxidation of the miscellaneous organics in the diluted waste in preference to the oxygen of sulfates. The exchanges are similar to those that take place when sodium nitrate is added to overloaded waste lagoons to prevent septic odors -- nitrate supplies oxygen and substitutes for sulfate which would be reduced if the nitrate were not present. Two of the three oxygen atoms in the nitrate radical are available. Thus, 5 ppm nitrate N will supply slightly more than 10 ppm oxygen, equivalent to water slightly less than 150 per cent saturated at summer temperatures of 30°C. (An equivalent concentration of nitrite N yields half as much oxygen.)

Complete biological reduction of nitrate yields nitrogen gas, and this excess of soluble nitrogen is driven off during aeration equilibrium with the atmosphere.

The daily sequence of stratification and oxygen depletion in the lower sections of the pond reduces the nitrate stored there to nitrogen gas. At the same time photosynthetic oxygen is being generated in the upper three to five feet of the stratified pond. During the night, while the pond is being air stirred, the excess oxygen of the upper layers is mixed with the deeper oxygen deficient waters, and supersaturation concentrations of nitrogen in the deeper layers is mixed with the surface waters.

The system has been operated in this fashion for the last five years; we have been unaware of the role of nitrification and denitrification processes, but it is now clear that they are critical elements in the control of hydrogen sulfide production in such periodically stratified process water holding ponds. It is also clear that photosynthesis may be used to provide oxygen for these processes. At the Hampstead site, mechanical aeration may be expected to provide not more than 45 lb of oxygen at maximum during each 12 hour cycle of operation. This would provide an increment of approximately 0.5 ppm dissolved oxygen to the low water volume of 11.3 million gallons of the pond per day. On the other hand, concentrations of 15 ppm dissolved oxygen generated in the upper five feet of the pond by photosynthesis, represents an increment of 684 lb of dissolved oxygen to the system, or approximately thirteen times that secured by low powered aeration mixing of the pond.

In short, the regime of stratification and aeration employed at the Hampstead plant pond to control hydrogen sulfide nuisance over the past five years has succeeded because it made maximum use of photosynthetic oxygen production, storage of oxygen as nitrate, and discharge of nutrient nitrogen as nitrogen gas.

4. Other Studies of Process Water Pond Biology

(1. Decomposition of Leaves in Pond.)

During the late autumn of 1965 substantial masses of hardwood leaves were blown into a peripheral drainage ditch of the Hampstead plant site and carried into the pond by winter storm water. The quantity of leaves was not determined, but it could be conservatively estimated that the

quantity entering the pond was at least equivalent to the fall from a mature stand of hardwoods equivalent to the pond's area; in short, the pond received one year's increment of forest floor.

This unanticipated addition was of concern (a) because of the possibilities of clogging the fine 10 ml screens of the process water supply system lifting water from the pond to the plant, and (b) the ultimate loss of volume and acceleration of swamp formation of the pond system.

Laboratory experiments were set up during the winter to study the rates of decay of hardwood leaves in oxygen low waters. These were not encouraging in that they indicated losses of organics from the leaves in the range of 2 per cent per month at 4°C, and a little more at 20°C. The leaves appeared to pickle themselves when stored in oxygen depleted water.

However, during the following months of 1965 until the preparation of this report, there were no incidents of leaf clogging of the fine intake filters, and no leaves were observed in the backwash water.

A shallow grab dredge study covering all parts of the pond bottom was made in late October, 1966, prior to the autumn leaf fall. At this time no identifiable leaf materials could be discovered in the mud samples.

The bottom mud itself proved to be high in organic matter -- samples ranged about 6.0 per cent organic carbon, as determined by wet combusion methods. The mud was also relatively rich in total phosphorus, about 1.2 per cent PO_4 dry weight, and comparatively poor in total nitrogen, about 0.3 per cent dry weight.

(2. Stabilization of Organics in Treated Waste by Chlorination) Some exploratory studies were made to see if diluted treated sewage could be biologically stabilized by chlorination. This work has not been satisfactorily completed but there are indications that concentrations of chlorine somewhat in excess of that required to establish breakpoint chlorination will inhibit growth of algae for a month or more in water samples seeded and stored in the light. These levels of chlorination yield measureable residues.

Rather oddly, when higher levels of chlorination are applied, residuals are lost and algae grow readily in water samples stored in the light.

This work will be carried forward under more controlled conditions when suitable analytical methods have been developed.

(3. Compatibility of Recycled Process Water and Coolant Materials) As part of the water economy program at the Hampstead plant, coolant waters used in grinding and machining are made in batch additions of water from the process water pond.

During the expansion of the plant in 1965, there were reports of foul odors at machine stations. This appeared to be due to anaerobic breakdown of the diluted coolant surfactants and dispersible oils used.

A study was made to examine the possible role of nutrient materials contained in process water in the fermentation of coolant materials. This showed that somewhat higher concentrations of bacteristatic agents were required to suppress bacterial breakdown of coolants

diluted with process water than was required for preservation of similar coolants diluted with distilled water. This effect was not related to the ammonia and phosphate content of the process water, however. It appeared that some other, unidentified component of the process water inactivated the bacteristatic agents used. Although effects on fermentability of the coolant waters could be demonstrated, it was not possible to develop odorous end products like those encountered in the plant.

(4. Review of Previous Water Reuse Projects) During the course of the first year's work a literature review of reports on operation of practical industrial reuse projects was made, a tabulation of loadings, treatment, and water quality data prepared, and a reprint file established. Although generally useful, none of the accounted projects involved the principle of nitrification and denitrification.

A file of papers on the design and behavior of oxidation ponds was also established.

(5. Graduate Student Studies) A graduate student project reviewing the design and performance of lagoon and oxidation ponds in the State of Maryland was completed and a master's thesis representing this work was presented.

A second master's thesis related to the project developed the engineering economics involved in reuse of treated waste waters for industrial purposes. Simplified formulations were developed to permit ready comparison of varieties of reuse with alternative sources of water.

(6. Development of Analytical Methods for Detailed Studies) A substantial amount of technical effort was spent during the year in the selection and development of analytical methods for use in routine and semi-automated analyses of the biological, chemical, and physical behavior of the waste treatment, storage, and recycle system of the plant. Special adaptations and simplifications are necessary to make these possible and practical -- especially for projected uses at other sites and more general uses. The ranges of concentration and variations in interfering substances complicate the nitrogen materials balance, especially.

(7. Development of Trailer Laboratory for Study) A twenty four foot office type trailer has been converted to a field laboratory and established at the side of the process pond. Work is under way to convert this into a semi-automated analytical system to follow changes in water quality during the cycles of stratification and mixing, and to establish materials and energy balances in the system.

(8. Heat Exchange Studies) Meteorological and temperature sensing equipment essential to measuring the performance of the process pond as a heat exchanger has been set up. This part of the project was made possible through the cooperation of the Edison Electric Institute. The principal use of process water and of the pond is for heat exchange; the mechanical features of the pond, the site, and local climatic factors are especially favorable for examining extreme conditions under natural, but relatively readily analyzed conditions.